(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 037 443 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
20.09.2000 Bulletin 2000/38

(51) Int. Cl.^{7}: **H04L 27/26**

(21) Application number: **00105711.6**

(22) Date of filing: **17.03.2000**

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: **17.03.1999 JP 7128699**

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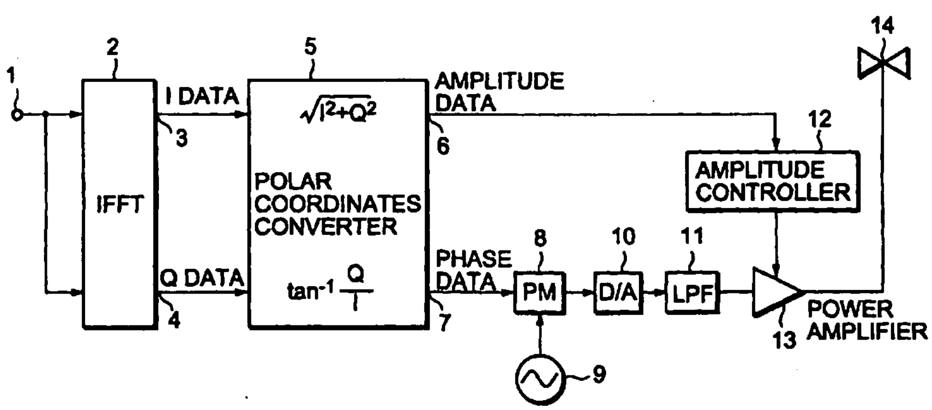
(54) OFDM modulator and digital broadcasting apparatus using the same

(57) An OFDM (Orthogonal Frequency Division Multiplexing) modulator of the present invention includes a polar coordinates converter to which real axis data and imaginary axis data output from a discrete inverse Fourier transformer are input. The converter converts the two kinds of input data to amplitude data to phase data. A carrier wave is subjected to phase modulation using the phase data and then input to a power amplifier as an input RF (Radio Frequency) signal. The power amplifier is implemented by a C class power amplifier having inherently high power utilization efficiency. The output level of the power amplifier is controlled in accordance with the amplitude data.

FIG.1



EP 1 037 443 A2

Description

BACKGROUND OF THE INVENTION

[0001] The present invention relates to a digital signal transmission apparatus and more particularly to an OFDM (Orthogonal Frequency Division Multiplexing) modulator and a digital broadcasting apparatus using the same.

[0002] A conventional OFDM digital broadcasting apparatus, particularly an OFDM modulator thereof, will be described with reference to FIG. 9. As shown, the OFDM modulator includes an input terminal 1 to which an input is applied, a discrete inverse Fourier transformer (IFFT) 2, two digital-to-analog converters (D/As) 10, two low pass filters (LPFs) 11, two modulators 23, a combiner 24, an A class or an AB class linear power amplifier 25, a 0°/90° phase distributor 26, and a carrier generator 9. The input applied to the input terminal 1 is a digital signal encoded by, e.g., an MPEG (Moving Picture coding Experts Group) 2 standard. The IFFT 2 transforms the input to I data and Q data which are a real axis component and an imaginary axis component, respectively. The I data and Q data each are input to one of the D/As 10. The D/As 10 respectively convert the I data and Q data input thereto to corresponding analog signals. The analog signals are then subjected to quadrature modulation. The power amplifier 25 amplifies the resulting modulated signal. The amplified signal output from the power amplifier 25 is sent via an antenna 14. As for the frequency spectrum, several hundreds to several thousands of carrier signals are distributed in the channel frequency band.

[0003] The problem with the above conventional broadcasting apparatus is that a multicarrier signal output from the OFDM modulator is amplified by the A class or AB class linear power amplifier 25, resulting in inefficient use of power. Specifically, as shown in FIG. 10, the peak level and mean level of the multicarrier signal are greatly different from each other. While the linear power amplifier 25 is used to amplify such a multicarrier signal with a minimum of distortion, the amplifier 25 has a mean output level which is about one-tenth of the peak output. The efficiency and therefore mean operation efficiency of the A class or AB class power amplifier 25 decreases with a decrease in output level.

SUMMARY OF THE INVENTION

[0004] It is therefore an object of the present invention to provide an OFDM modulator which enables a digital broadcasting apparatus capable of efficiently amplifying a multicarrier signal output.

[0005] It is further an object of the present invention to provide a digital broadcasting apparatus capable of efficiently amplifying a multicarrier signal output from the above OFDM modulator.

[0006] In accordance with the present invention, an OFDM modulator includes circuitry for converting real axis data and imaginary axis data output from a discrete inverse Fourier transformer to amplitude data and phase data on polar coordinates, and modulating the phase of a carrier wave on the basis of the phase data.

[0007] Also, in accordance with the present invention, a digital broadcasting apparatus includes the above OFDM modulator, and a power amplifier for executing amplitude modulation with the carrier wave output from the OFDM modulator with the amplitude data also output from the OFDM modulator.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description taken with the accompanying drawings in which:

FIG. 1 is a block diagram schematically showing a digital broadcasting apparatus embodying the present invention;
FIG. 2 shows I data and Q data in the form of polar coordinates;
FIGS. 3A and 3B are circuit diagrams each showing a particular specific configuration of a power amplifier included in the illustrative embodiment;
FIG. 4 is a graph showing the efficiency characteristic of a voltage-controlled C class power amplifier;
FIG. 5 is a schematic block diagram showing an alternative embodiment of the present invention;
FIG. 6 is a graph showing imaginary combined power available with the alternative embodiment;
FIG. 7 is a graph showing the combined efficiency characteristic of N power amplifiers included in the alternative embodiment;
FIGS. 8A and 8B are circuit diagrams showing a specific configuration of a combiner included in the alternative embodiment;
FIG. 9 is a schematic block diagram showing a conventional OFDM digital broadcasting apparatus; and
FIG. 10 is a graph showing the efficiency characteristic of an AB class power amplifier included in the broadcasting apparatus of FIG. 9.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0009] First, the principle of the present invention on which illustrative embodiments to be described are based will be described. Assume that a discrete inverse Fourier transformer outputs COS(ωst) = I data and SIN(ωst) = Q data. Then, these outputs may be converted to polar coordinates data:

$$\text{amplitude data: } r = \sqrt{I^2+Q^2} = \sqrt{\cos^2(\bar{\omega}_s t)+\sin^2(\bar{\omega}_s t)}=1$$

$$\text{phase data: } \vartheta = \tan^{-1}\frac{Q}{I} = \tan^{-1}\frac{\sin(\bar{\omega}_s t)}{\cos(\bar{\omega}_s t)} = \bar{\omega}_s t$$

When the phase of a carrier wave Vc*COS(ωct) is modulated by the phase data, there is produced:

$$Vc \cdot COS(\omega ct - \theta)$$

[0010] The above phase-modulated carrier wave is input to a power amplifier. The output of the power amplifier is controlled on the basis of the amplitude data produced by the polar coordinates conversion, thereby effecting amplitude modulation. In this sense, the power amplifier plays the role of a multiplexer and outputs the following product:

$$\begin{aligned} & r \cdot Vc \cdot COS(\omega c - \theta) = 1 \cdot Vc'COS(\omega ct - \omega st) \\ & = Vc \cdot COS\{(\omega c - \omega s) \cdot t\} \\ & = Vc \cdot COS\{(\omega c - \omega s) \cdot t\} \end{aligned}$$

[0011] The above output of the power amplifier has a single sideband (SSB) waveform identical with the following waveform produced by modulating the I data = COS(ωst) and Q data = SIN(ωst) with Vc*COS(ωct) by quadrature modulation:

$$COS(\omega st) \cdot Vc \cdot COS(\omega ct) + SIN(\omega st) \cdot Vc \cdot COS(\omega ct + \pi/2) = Vc \cdot Cos\{(\omega c - \omega s)t\}$$

It follows that by transforming the outputs of the discrete inverse Fourier transformer to amplitude data and phase data and then executing the above procedure, it is possible to output a waveform identical with one available with the conventional technology.

[0012] While the amplifier is caused to perform C class operation, an amplitude control circuit constantly controls the operation to a saturation level and thereby controls an output amplitude. This allows even a nonlinear C class amplifier to produce a linear output and insures high efficiency of the C class operation.

[0013] Referring to FIG. 1, a digital broadcasting apparatus embodying the present invention is shown and includes an IFFT 2. I data 3 and Q data 4 output from the IFFT 2 are input to a polar coordinates converter 5 and converted to amplitude data 6 and phase data 7 thereby. FIG. 2 shows a relation between the I data 3 and Q data and the amplitude data 6 and phase data 7. A phase modulator (PM) 8 modulates a carrier signal output from a carrier generator 9 with the phase data 7. The modulated carrier signal is then converted to an analog signal by a D/A 10 and filtered by an LPF 11. The resulting output of the LPF 11 is input to a power amplifier 13 as an input RF (Radio Frequency) signal.

[0014] The power amplifier 13 is caused to perform C class operation while the input RF signal is maintained at a constant level. FIGS. 3A and 3B each show a particular specific configuration of the power amplifier 13. An FET (Field Effect Transistor) 27 and a bipolar transistor 28 shown in FIGS. 3A and 3B each are an amplifying device. The drain voltage or the collector voltage of the FET 27 or that of the bipolar transistor 28 is varied to vary the level of the output signal of the power amplifier 13. In this case, as shown in FIG. 4, so long as the output level of the drain voltage or that of the collector voltage is above a certain level, a constant efficiency is achievable without regard to the variation of the output signal level. An OFDM digital modulated wave is produced by controlling the output level of the power amplifier 12 on the basis of the previously stated amplitude data and effecting amplitude modulation.

[0015] FIG. 5 shows an alternative embodiment of the present invention. As shown, the I data 3 and Q data 4 output from the IFFT 2 are input to the polar coordinates converter 5 as in the previous embodiment. The IFFT 2 converts the I data 3 and Q data 4 to the amplitude data 6 and phase data 7. Finally, the amplitude data 6 and phase-modulated carrier wave is produced.

[0016] As shown in FIG. 5, the illustrative embodiment includes a power amplifying section made up of a distributor 21, N switches 22, N C class power amplifiers 15, a combiner 20, and an amplitude controller 12'. The distributor 21 distributes the RF signal input thereto to N outputs thereof. The switches 22 each ON/OFF control one of the N RF sig-

nals. The power amplifiers 15 each have an output which is a 2^N ratio. The combiner 20 combines the outputs of the power amplifiers 15. The amplitude controller 12' controls the combiner 20 and switches 22. The power amplifiers 15 each have a particular output weight. FIG. 6 shows specific output weights PA1, PA2, PA3 and so forth assigned to the power amplifiers 15.

[0017] In operation, the switches 22 each ON/OFF control the RF signal input thereto on the basis of a digital signal representative of the amplitude data 6. The combiner 20 therefore combines only the outputs of the power amplifiers 15 whose inputs are in an ON state, thereby producing an output corresponding to the amplitude data. Consequently, as shown in FIG. 7, the level of the output signal can be varied on the basis of the combination of ON/OFF states of the power amplifiers 15. That is, amplitude modulation is effected by using the amplitude data 6 (see FIG. 6). In this case, the efficiency always has a peak value because the power amplifiers 15 in the ON state are performing C class operation.

[0018] FIGS. 8A and 8B show a specific configuration of the combiner 20. Specifically, FIGS. 8A and 8B respectively show the basic portion and the overall configuration of the combiner 20. As shown in FIG. 8A, the basic portion includes two 3 dB couplers 16 and 18 and a phase shifter 17. As shown in FIG. 8B, the general configuration has such basic portions equal in number to the power amplifiers 15 connected in series.

[0019] In the basic portion, when two signals different in power level from each other are input to the first 3 dB coupler 16 with the same phase, the amplitudes are averaged with the result that signals with the same amplitude are output from the coupler 16. Because the phase depends on the difference in level between input power, the phase shifter 17 gives the output signals of the coupler 16 a relative phase difference of 90°, i.e., delivers signals identical in amplitude, but different in phase by 90°, to the second 3 dB coupler 18. As a result, all the outputs are delivers to an output terminal 31. Although the level of the signal input to the individual basic portion of the combiner 20 depends on whether or not the output signal of the associated power amplifier 15 is present, it is possible to combine power without any loss by controlling the phase shifters 17.

[0020] In summary, in accordance with the present invention, an OFDM digital broadcasting apparatus transforms an input signal to polar coordinates representative of amplitude data and phase data, modulates a carrier wave in accordance with the phase data, and varies the level of the carrier wave in accordance with the amplitude data. The apparatus is therefore capable of utilizing power more efficiently than the conventional OFDM digital broadcasting apparatus.

[0021] Various modifications will become possible for those skilled in the art after receiving the teachings of the present disclosure without departing from the scope thereof.

Claims

1. An OFDM (Orthogonal Frequency Division Multiplexing) modulator comprising:

   circuitry for converting real axis data and imaginary axis data output from a discrete inverse Fourier transformer to amplitude data and phase data on polar coordinates, and modulating a phase of a carrier wave on the basis of said phase data.

2. A digital broadcasting apparatus comprising:

   an OFDM modulator comprising circuitry for converting real axis data and imaginary axis data output from a discrete inverse Fourier transformer to amplitude data and phase data on polar coordinates, and modulating a phase of a carrier wave on the basis of said phase data; and
   a power amplifier for executing amplitude modulation with the carrier wave output from said OFDM modulator with said amplitude data also output from said OFDM modulator.

3. An apparatus as claimed in claim 2, wherein said power amplifier comprises an amplifying device implemented by either one of a bipolar transistor and an FET capable of performing a C class operation, a collector voltage or a drain voltage of said amplifying device being controlled on the basis of said amplitude data to thereby execute the amplitude modulation.

4. An apparatus as claimed in claim 2, wherein said power amplifier comprises N power amplifying units each having an output of 2^N radio and capable of performing a C class operation, said apparatus further comprising N switches for respectively ON/OFF controlling inputs to said N power amplifying units, a combiner comprising N circuits each including two 3 dB couplers and a phase shifter, and a control circuit for controlling said switches and said phase shifter in accordance with said amplitude data.

5. An apparatus as claimed in claim 2, wherein said power amplifier comprises a plurality of power amplifying circuits capable of performing a C class operation and different in output from each other, said apparatus further comprising a combiner for combining outputs of said plurality of power amplifying circuits, a combination of operations of said plurality of power amplifying circuits being controlled by said amplitude data.

FIG.1

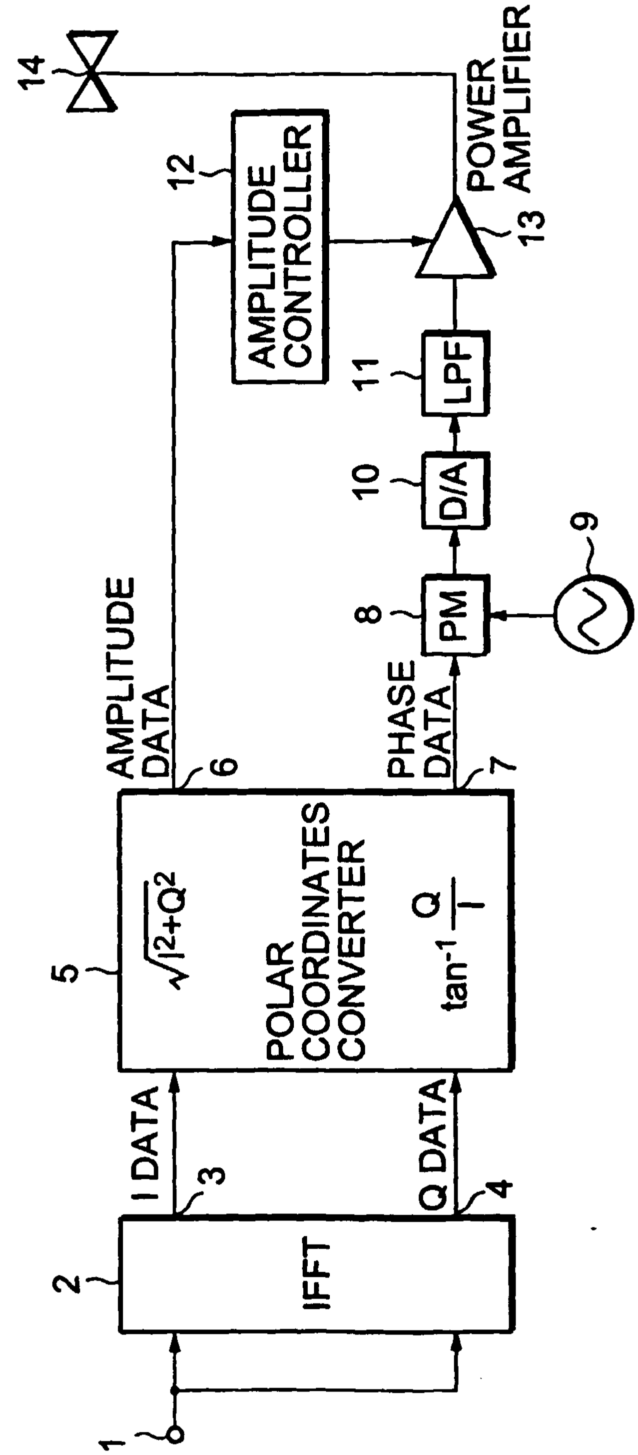
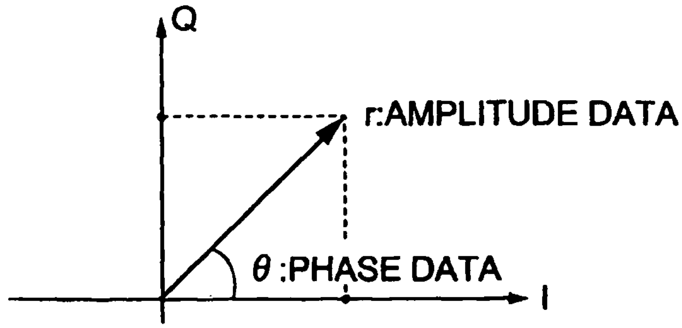

1
2
IFFT
3
I DATA
4
Q DATA
5
√I2+Q2
POLAR COORDINATES CONVERTER
tan-1 Q/I
6
AMPLITUDE DATA
7
PHASE DATA
8
PM
9
10
D/A
11
LPF
12
AMPLITUDE CONTROLLER
13
POWER AMPLIFIER
14

FIG.2



CONVERSION TO POLAR COORDINATES

FIG.3A

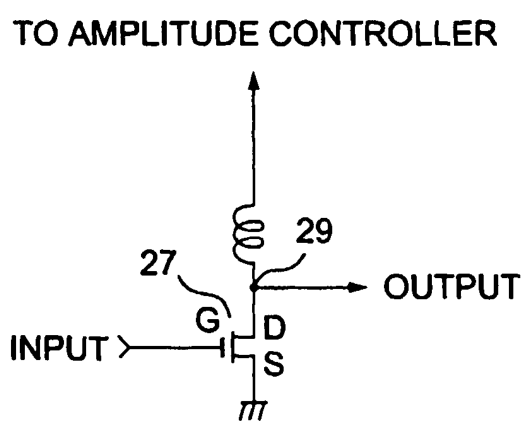


FIG.3B

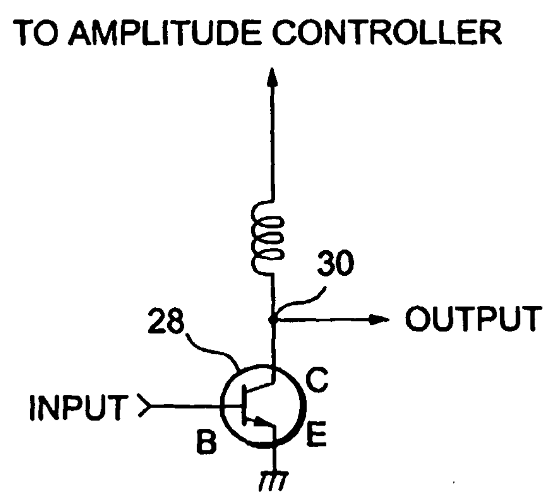


FIG.4

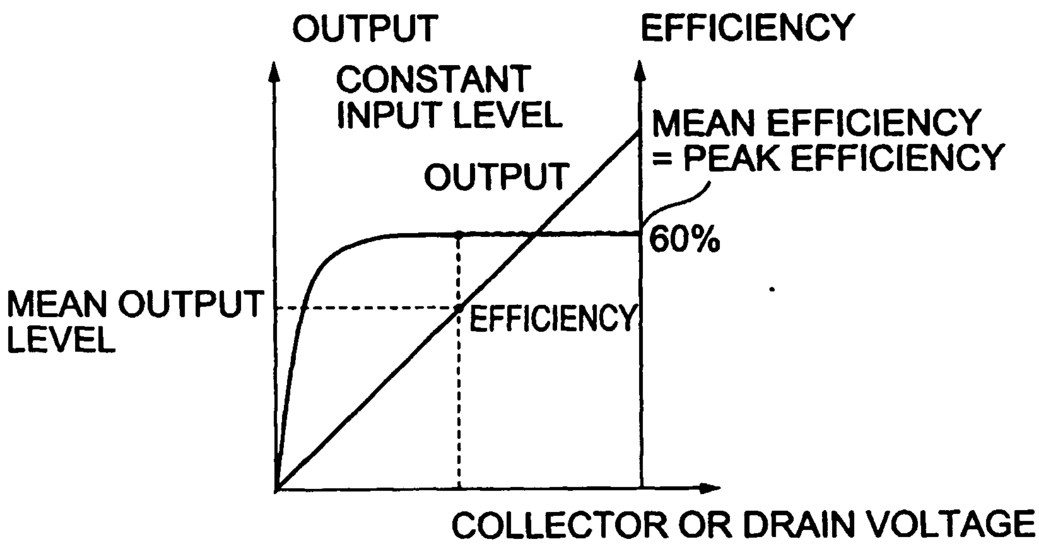

OUTPUT
EFFICIENCY
CONSTANT
INPUT LEVEL
MEAN EFFICIENCY
= PEAK EFFICIENCY
OUTPUT
60%
MEAN OUTPUT
LEVEL
EFFICIENCY
COLLECTOR OR DRAIN VOLTAGE

FIG. 5

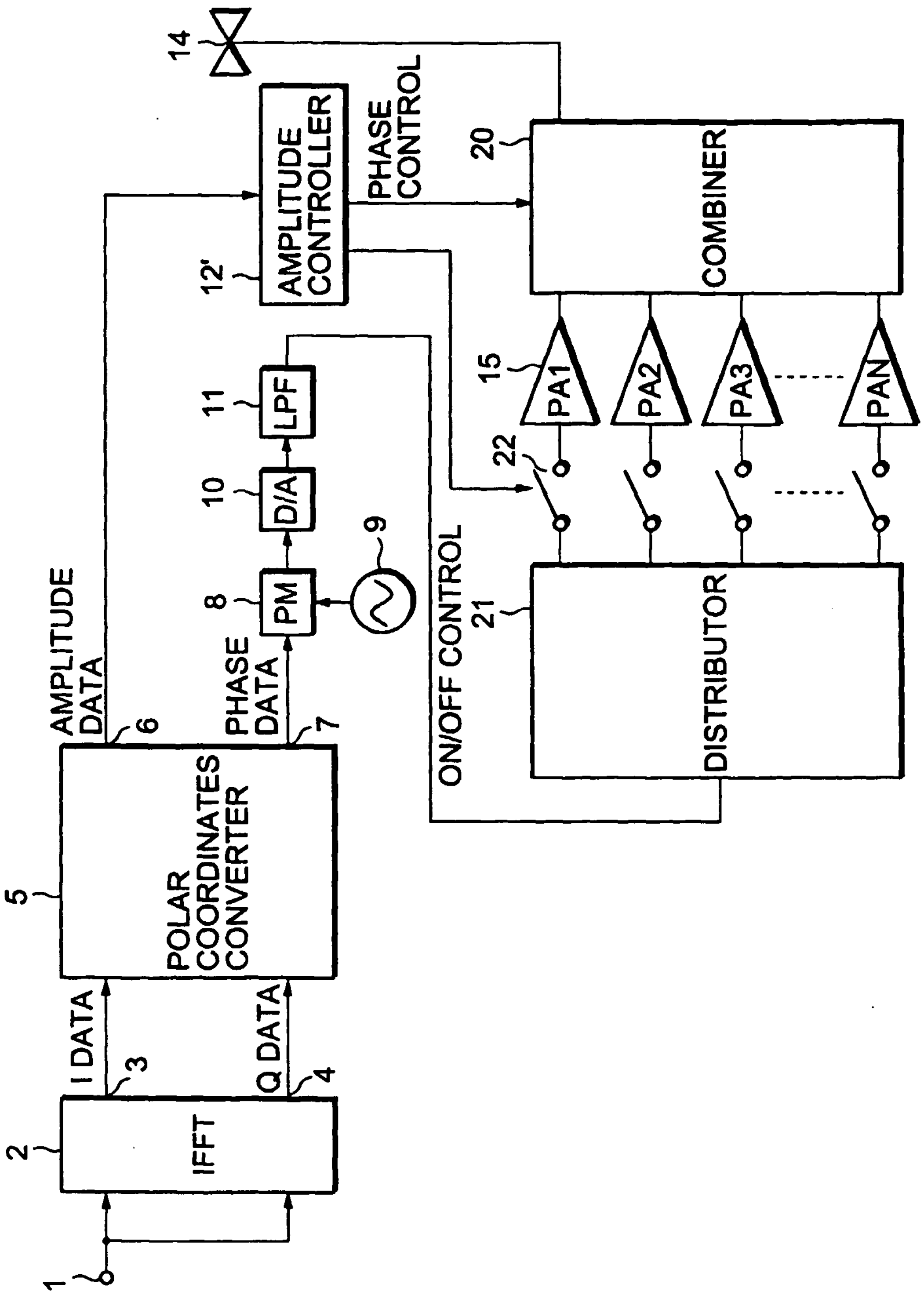

1
2
IFFT
I DATA
3
Q DATA
4
5
POLAR COORDINATES CONVERTER
AMPLITUDE DATA
6
PHASE DATA
7
8
PM
9
10
D/A
11
LPF
12'
AMPLITUDE CONTROLLER
PHASE CONTROL
14
20
COMBINER
15
PA1
PA2
PA3
PAN
22
ON/OFF CONTROL
21
DISTRIBUTOR

FIG.6

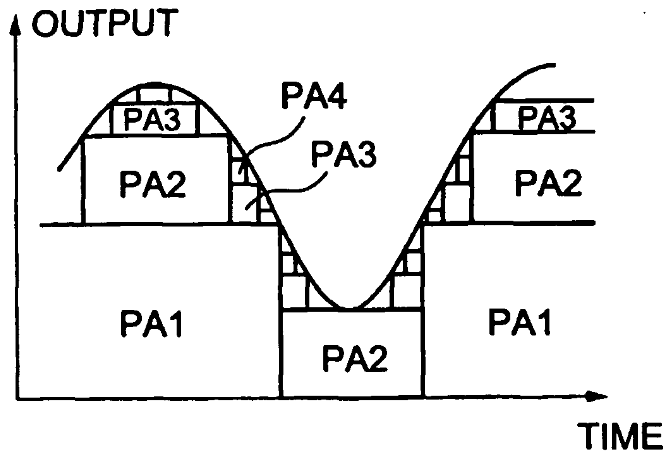

OUTPUT
PA3
PA4
PA3
PA3
PA2
PA2
PA1
PA2
PA1
TIME

FIG.7

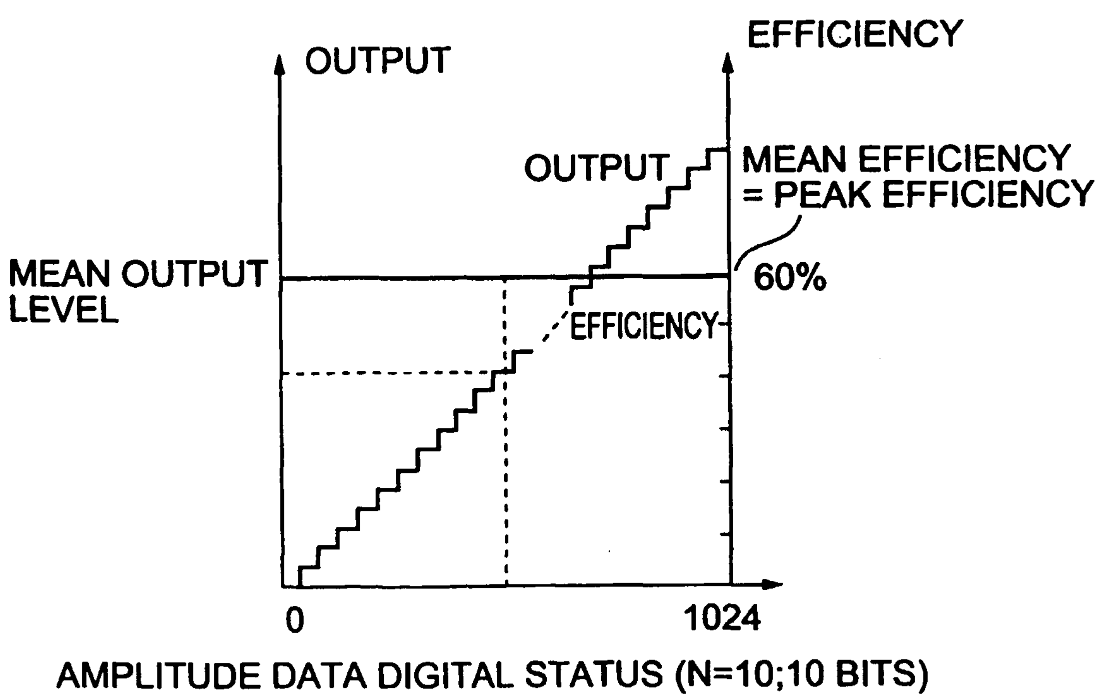

OUTPUT
EFFICIENCY
OUTPUT
MEAN EFFICIENCY
= PEAK EFFICIENCY
MEAN OUTPUT
LEVEL
60%
EFFICIENCY
0
1024
AMPLITUDE DATA DIGITAL STATUS (N=10;10 BITS)

FIG.8A

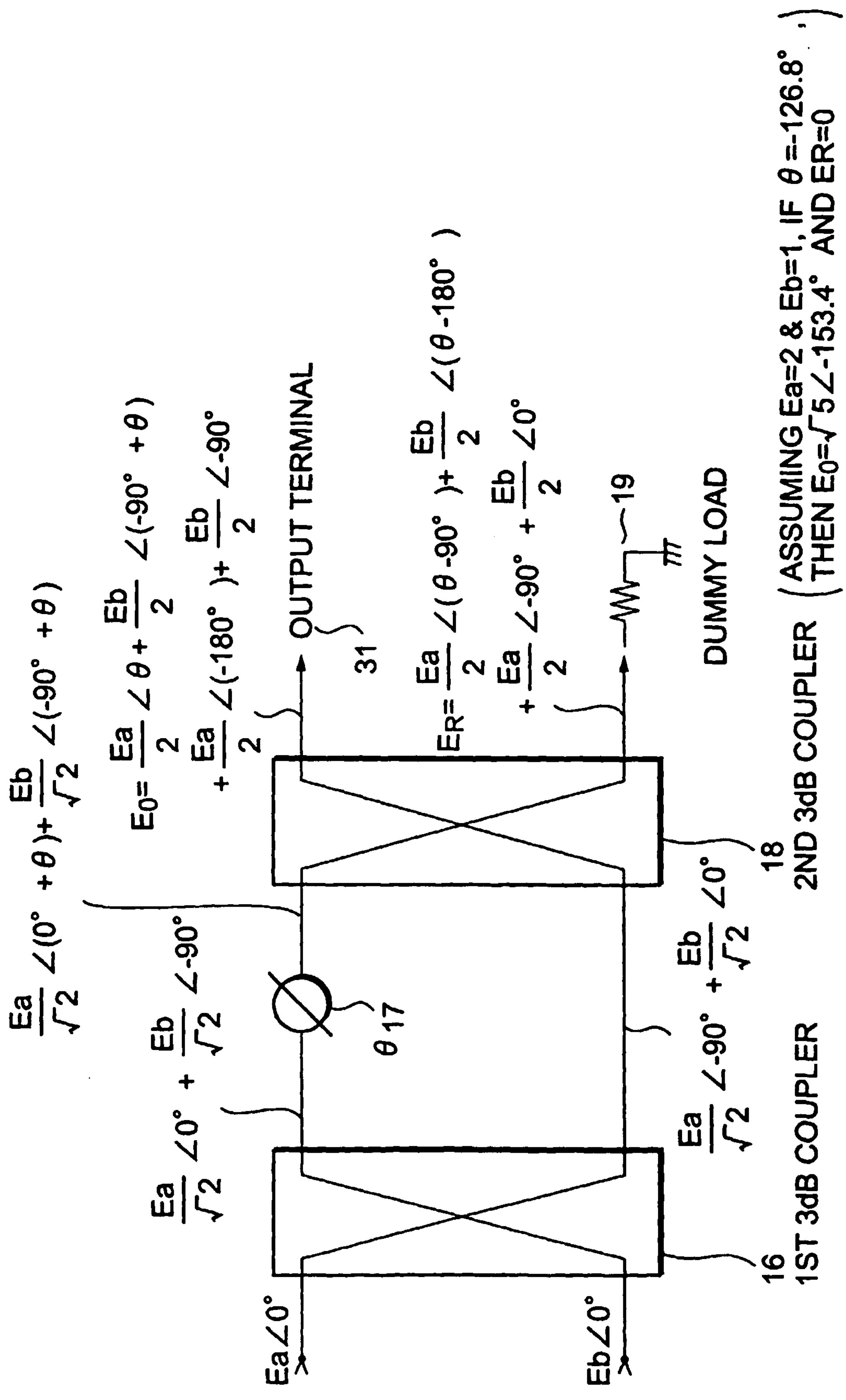

Ea∠0°
Eb∠0°
1ST 3dB COUPLER
16
2ND 3dB COUPLER
18
θ 17
OUTPUT TERMINAL
31
DUMMY LOAD
19
$\frac{Ea}{\sqrt{2}}\angle 0° + \frac{Eb}{\sqrt{2}}\angle -90°$
$\frac{Ea}{\sqrt{2}}\angle -90° + \frac{Eb}{\sqrt{2}}\angle 0°$
$\frac{Ea}{\sqrt{2}}\angle(0° + \theta) + \frac{Eb}{\sqrt{2}}\angle(-90° + \theta)$
$E_0 = \frac{Ea}{2}\angle\theta + \frac{Eb}{2}\angle(-90° + \theta) + \frac{Ea}{2}\angle(-180°) + \frac{Eb}{2}\angle -90°$
$E_R = \frac{Ea}{2}\angle(\theta - 90°) + \frac{Eb}{2}\angle(\theta - 180°) + \frac{Ea}{2}\angle -90° + \frac{Eb}{2}\angle 0°$
(ASSUMING Ea=2 & Eb=1, IF θ=-126.8°,
THEN $E_0=\sqrt{5}\angle -153.4°$ AND ER=0)

FIG.8B

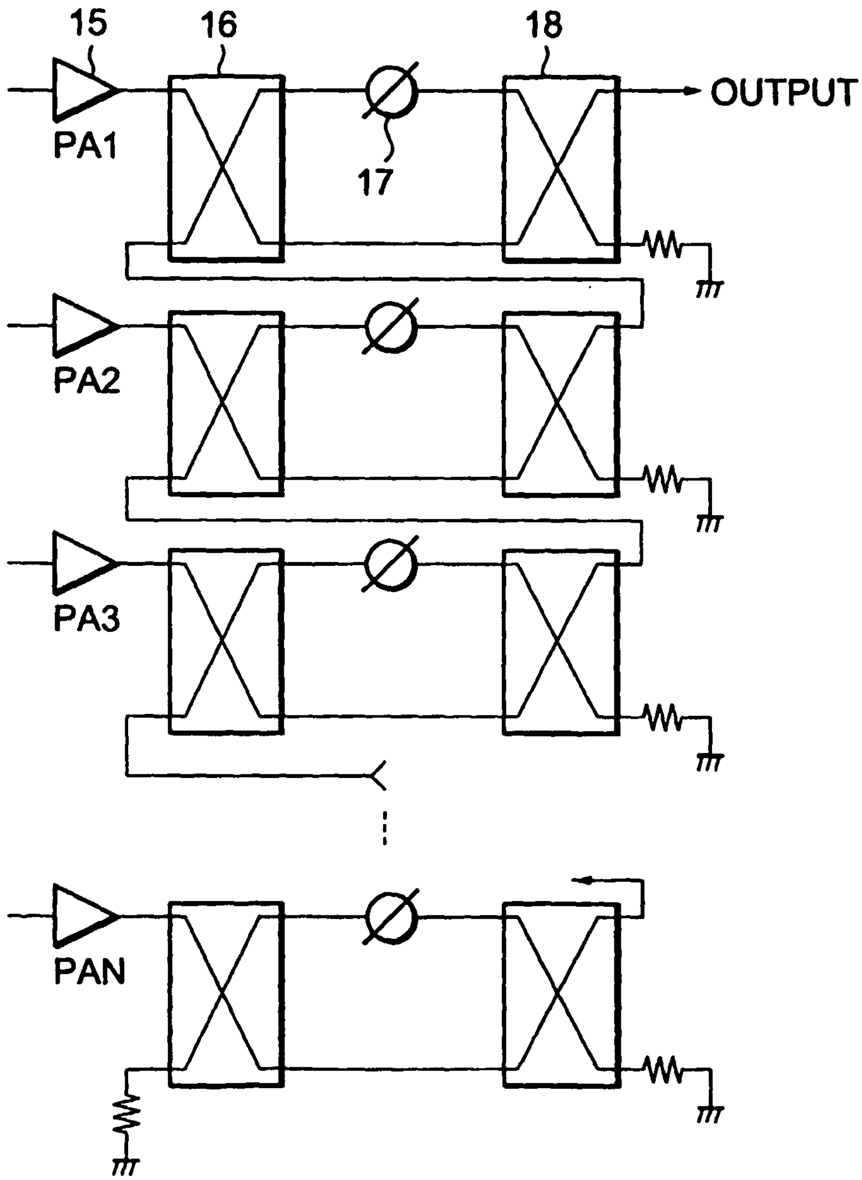


FIG.9
PRIOR ART

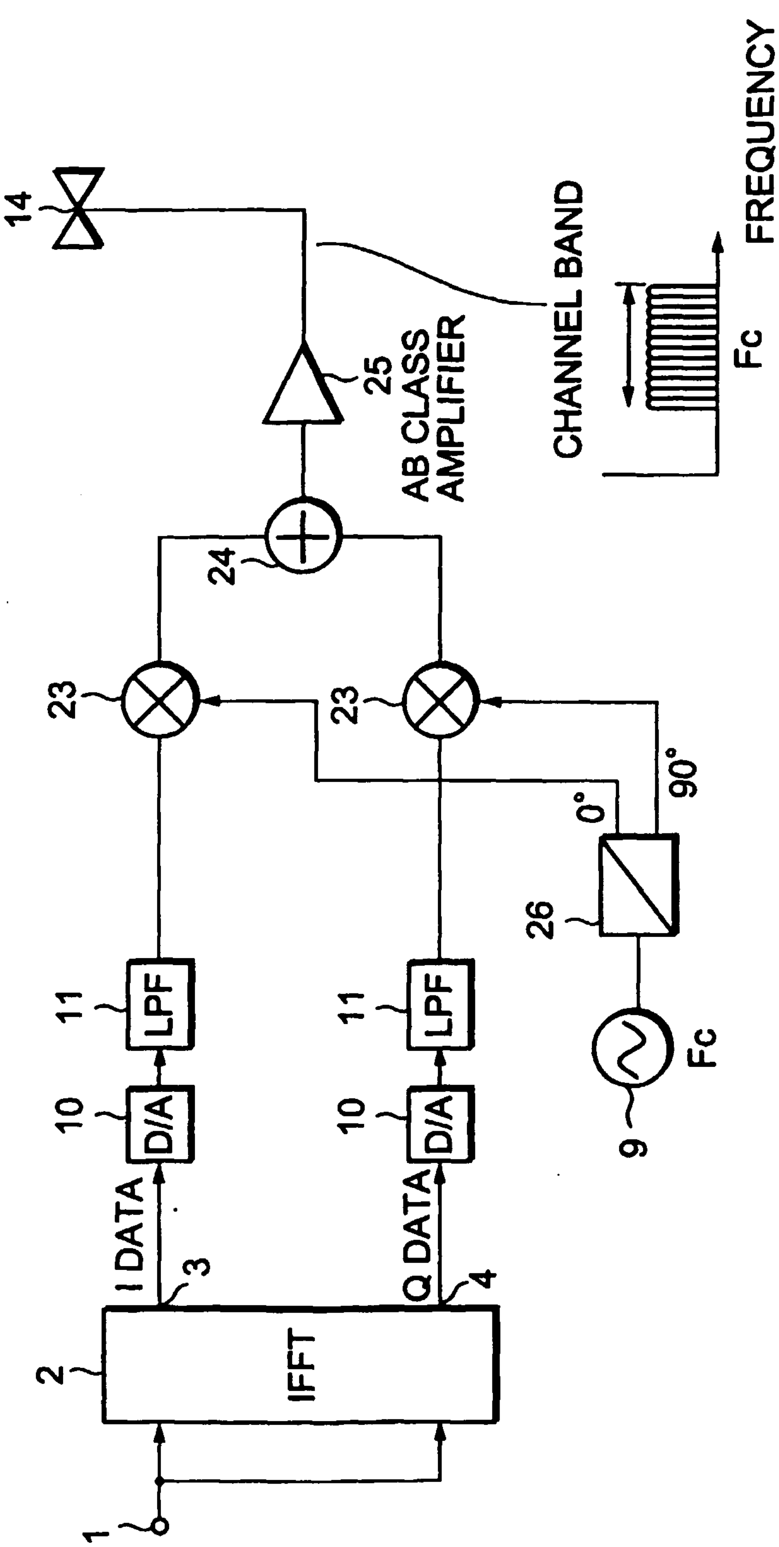
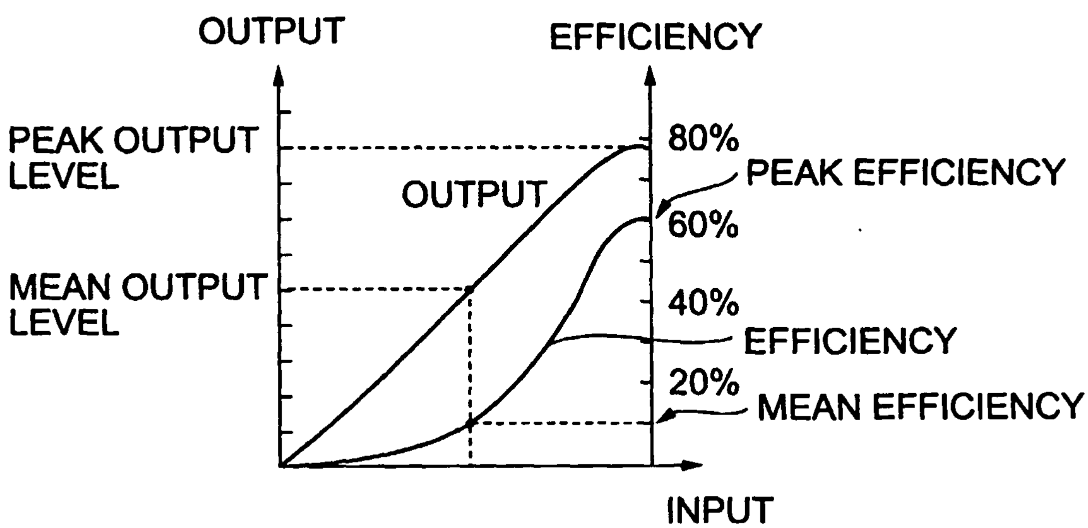


FIG.10


OUTPUT
EFFICIENCY
PEAK OUTPUT LEVEL
OUTPUT
80%
PEAK EFFICIENCY
60%
MEAN OUTPUT LEVEL
40%
EFFICIENCY
20%
MEAN EFFICIENCY
INPUT